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Technical Report ECOM-01698-9

LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

PROGRESS REPORT

by

L. Lesensky - M. Arnum
C. McGeoch

May 1968

ECOM

UNITED STATES ARMY ELECTRONICS COMMAND · FORT MONMOUTH, N.J.

Contract DA28-043-AMC-01698 (E)

SPONSORED BY: ADVANCED RESEARCH PROJECTS AGENCY
ARPA ORDER NO. 345

RAYTHEON COMPANY
MICROWAVE AND POWER TUBE DIVISION
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LONG-LIFE COLD CATHODE STUDIES FOR CROSSED-FIELD TUBES

Ninth Quarterly Report

15 October 1967 to 15 January 1968

Report No. 9
Contract No. DA28-043-AMC-01698(E)
DA Project No. 7900-21-223-12-00

Prepared by

L. Lesensky
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C. McGeoch

RAYTHEON COMPANY
Microwave and Power Tube Division
Waltham, Massachusetts 02154

For

U.S. Army Electronics Command
Fort Monmouth, N.J. 07703

Sponsored by

Advanced Research Projects Agency
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ABSTRACT

Further tests of the effects of high current-density electron bombardment (0.75 A/cm^2) and of residual oxygen ($\sim$ 5 x 10^{-6} Torr) on the secondary-emission ratio (δ) were performed in the Electron Bombardment Vehicle (EBV) for the following samples:

1. Three samples of 9500 Å evaporated aluminum on copper.

2. Two samples of 300 Å Al_2O_3 on Al, anodically oxidized in tartaric acid.

Generally, δ_{max} varied from approximately 3.0 to 1.5. All samples showed good recovery due to O_2 and consistent degradation of δ due to electron bombardment.

Test of the QKS1397 CFA vehicle for more than 50 hours has demonstrated stabilized cathode emission from an aluminum cold cathode through the use of oxygen in the pressure range of 10^{-6} to 10^{-5} Torr. The stabilized emission level reached was approximately 4 A/cm^2 at a duty cycle of 0.001.

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1. INTRODUCTION

The objective of the present cold cathode study program is to achieve long life cold-cathode performance for crossed-field amplifiers. This program is being performed for the United States Army Electronics Command, Fort Monmouth, New Jersey, under contract DA-28-043-AMC-01698(E).

In this study, selected cold cathode materials will be evaluated as to their secondary emission properties, their ability to withstand environmental factors expected in a crossed-field amplifier, and their crossed-field amplifier performance. Based on the above experimental information and pertinent theoretical calculations, a life prediction chart will be established for a number of cold cathode materials.

The program is divided into two concurrent phases, Phase A being concerned with the measurement of various pertinent properties of cold cathode materials outside of the tube environment, and Phase B involving the evaluation and life testing of selected cathodes in a crossed-field amplifier.

The first quarterly report of this contract (Technical Report ECOM 01698-1) contains a discussion of the objectives and plans for the over-all program. Quarterly Report No. 5 contains a description of the CFA test vehicles used in this program.

2. PHASE A - MATERIALS EVALUATION

2.1 Electron Bombardment Evaluation. During the present quarter, a number of samples were evaluated in the Electron Bombardment Vehicle (EBV), involving primarily the effect on secondary emission ratio (δ) of high current-density electron bombardment (up to 0.75 A/cm^2) and recovery with oxygen. These samples were as follows:

a. 9500 Å layer of aluminum evaporated on copper.

1. Completion of sample E-1 (13 hours additional)
2. Sample E-2 (80 hours)
3. Sample E-3 (26 hours)

b. 300 Å aluminum-oxide layer on aluminum (anodically oxidized, using tartaric acid)

1. Sample A-1 (6061 Al) (60 hours)
2. Sample A-2 (1100 Al) (55 hours)

In addition to the evaluation of the above samples in the cold EBV, an impregnated tungsten sample was evaluated briefly in the Hot/Cold EBV for 9 hours.

2. 1. 1 <u>Electron Bombardment Vehicle (EBV) Testing of Evaporated Al on Cu Samples.</u>

2. 1. 1. 1 <u>Sample E-1.</u> Sample E-1 consisted of an evaporated aluminum layer (9500 Å) deposited on a chemically cleaned, wet-polished OFHC copper substrate. Samples E-2 and E-3, discussed below, were prepared in the same way.

E-1 data were reported in the 8th Quarterly Report (see Figure 4 therein) and are reproduced here as Figure 1. An additional 13 hours of

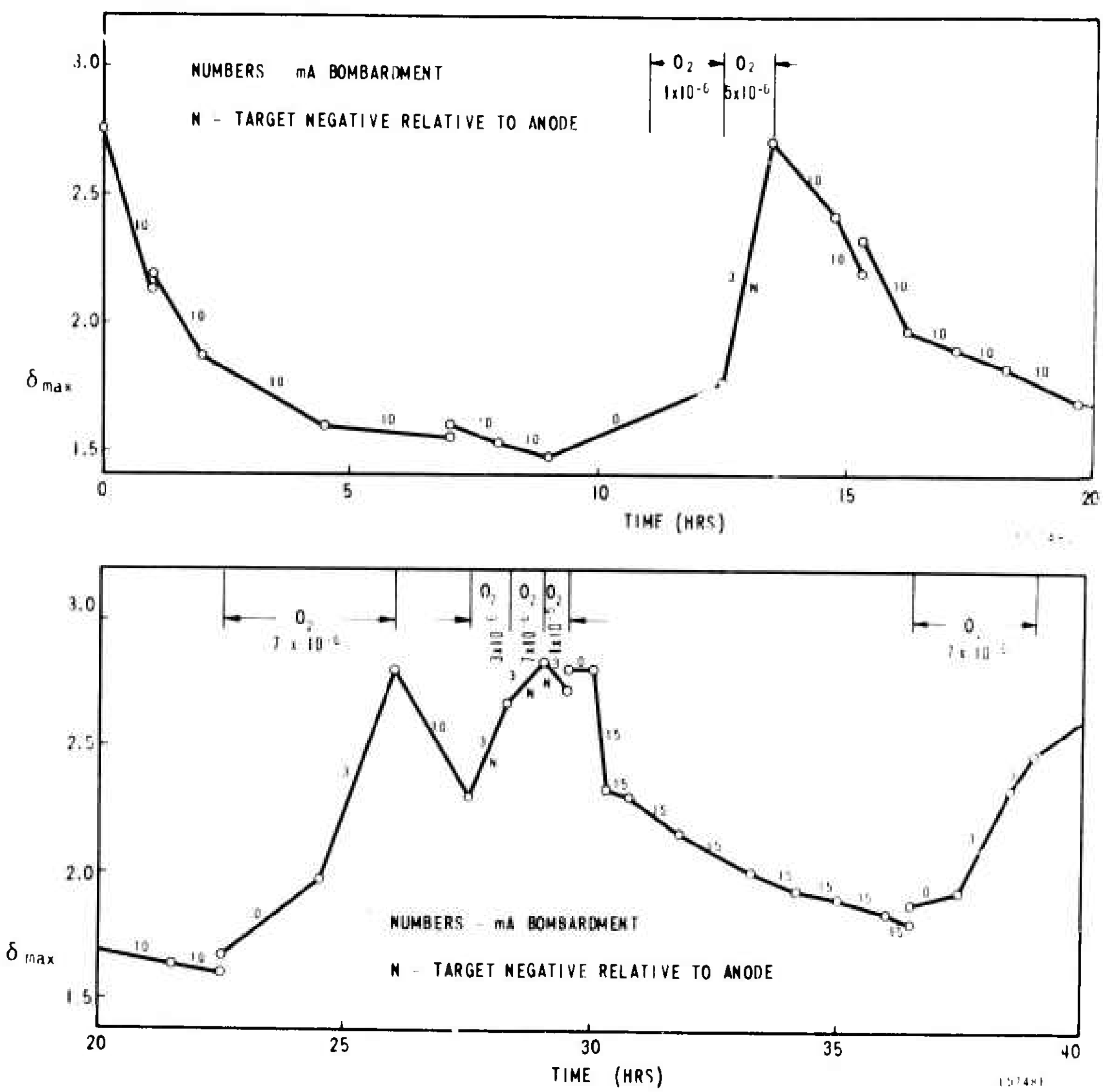


Figure 1 δ_{max} vs EBV Time for 9500Å Evaporated Aluminum on Copper

EBV data for E-1 are shown in Figure 2. The decrease of δ_{max} due to the same sample. δ_{max} decreased from 2.5 to 1.7 in five hours. Recovery of δ with O_2 was rapid with electron bombarding at 0.15 A/cm^2, but negligible without electron bombardment. As suggested before, this difference in re-oxidation rates is believed to be due to the temperature difference.

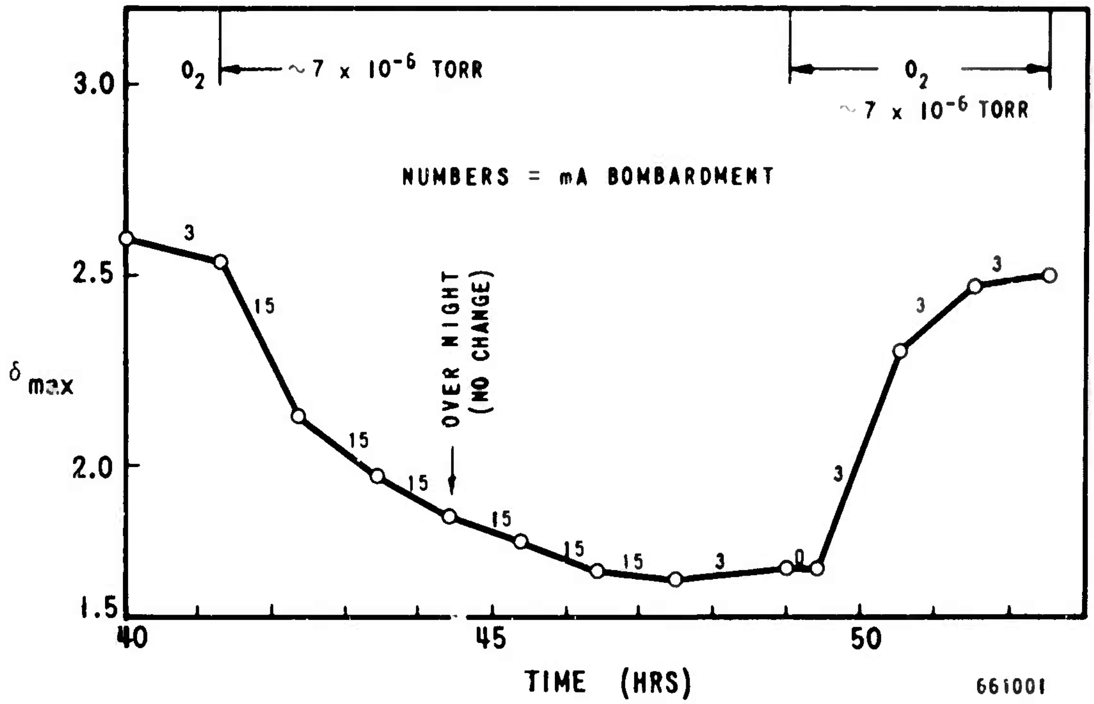


Figure 2. δ_{max} vs EBV Time for 9500Å Evaporated Aluminum on Copper (Sample E 1)

2.1.1.2 Sample E-2. Sample E-2 was similar to E-1, consisting of a 9500Å layer of aluminum evaporated on copper. The results of 80 hours of evaluation in the EBV are shown in Figure 3. Residual vacuum without oxygen addition was approximately 5 x 10^{-8} Torr. Recovery with oxygen at 8 x 10^{-6} Torr is shown during hours three to 11. After a small increase (overnight) while equipment (including gun) was off, a large increase to a δ_{max} in excess of 4.0 was observed. During this time, the gun heater and gun cathode were at temperature but without electron bombardment. The increase may have been due to gases released by the heater-cathode structure of the electron gun. Subsequent to this, electron bombardment at 0.75 A/cm^2 from hours 19 to 35 caused δ_{max} to decrease from 4.0 to 1.4. This sample never again reached this high a δ value. The sample continued to show the expected response to O_2 and to high-density electron bombardment. The decrease of δ_{max} due to bombardment at 0.75 A/cm^2 which occurred during hours 60-79 was quite slow. δ_{max} decreased from 3.2 to 1.5 in 24 hours.

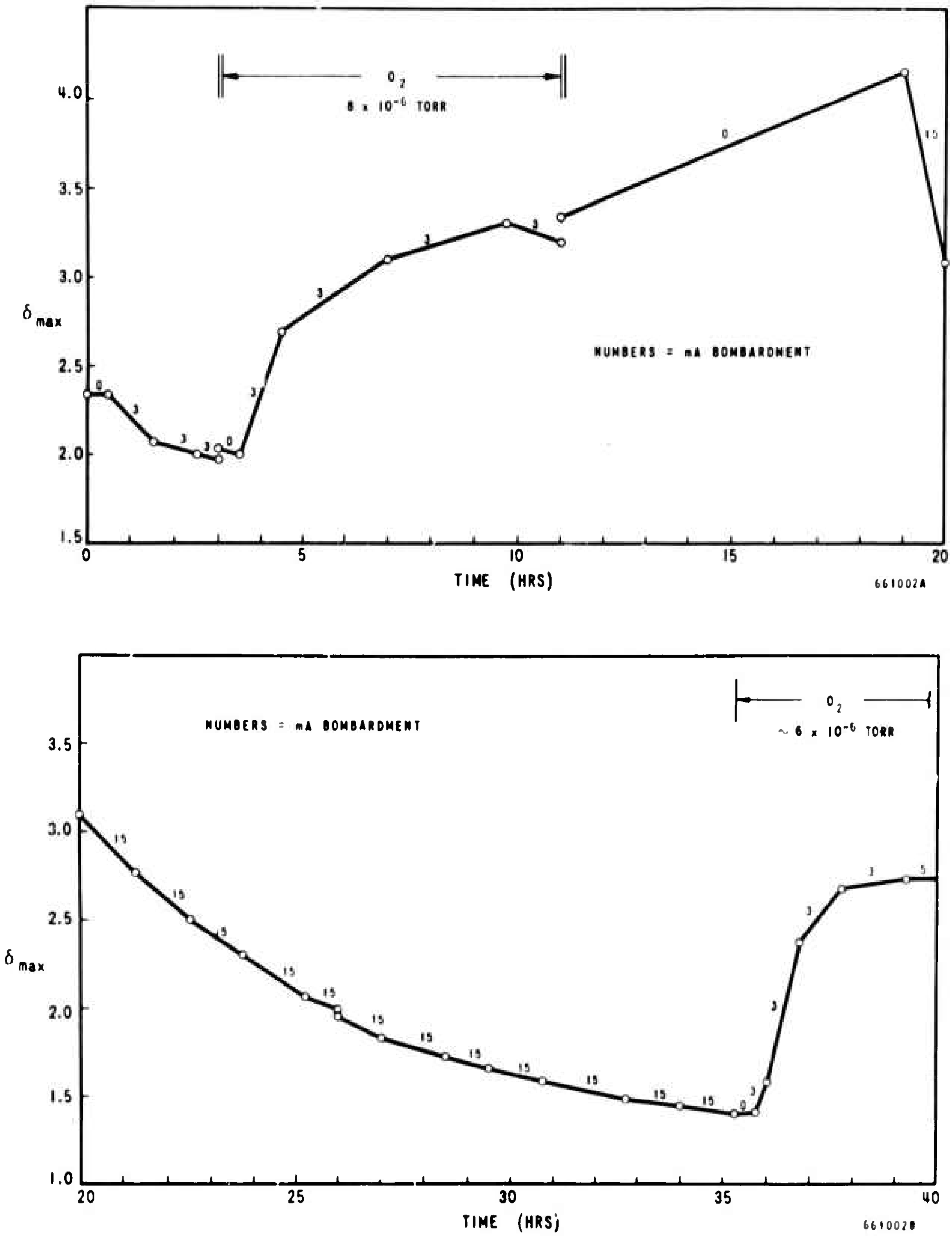
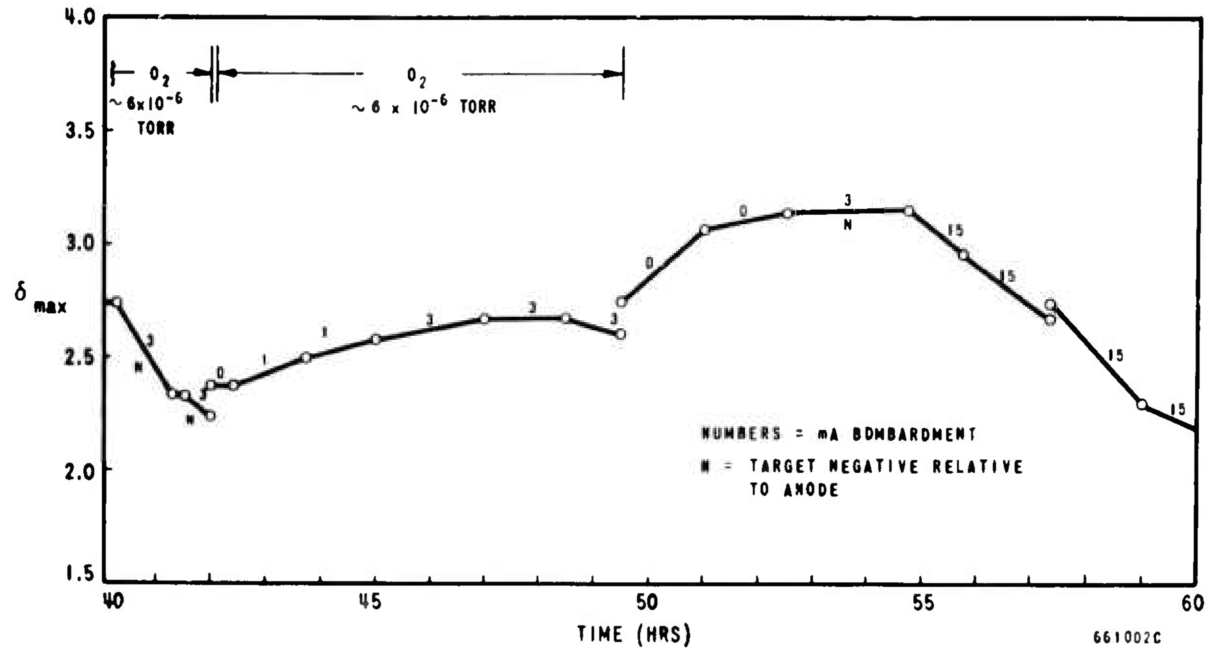


Figure 3. δ_{max} vs EBV Time for 9500Å Evaporated Aluminum on Copper (Sample E-2)

Sheet 1



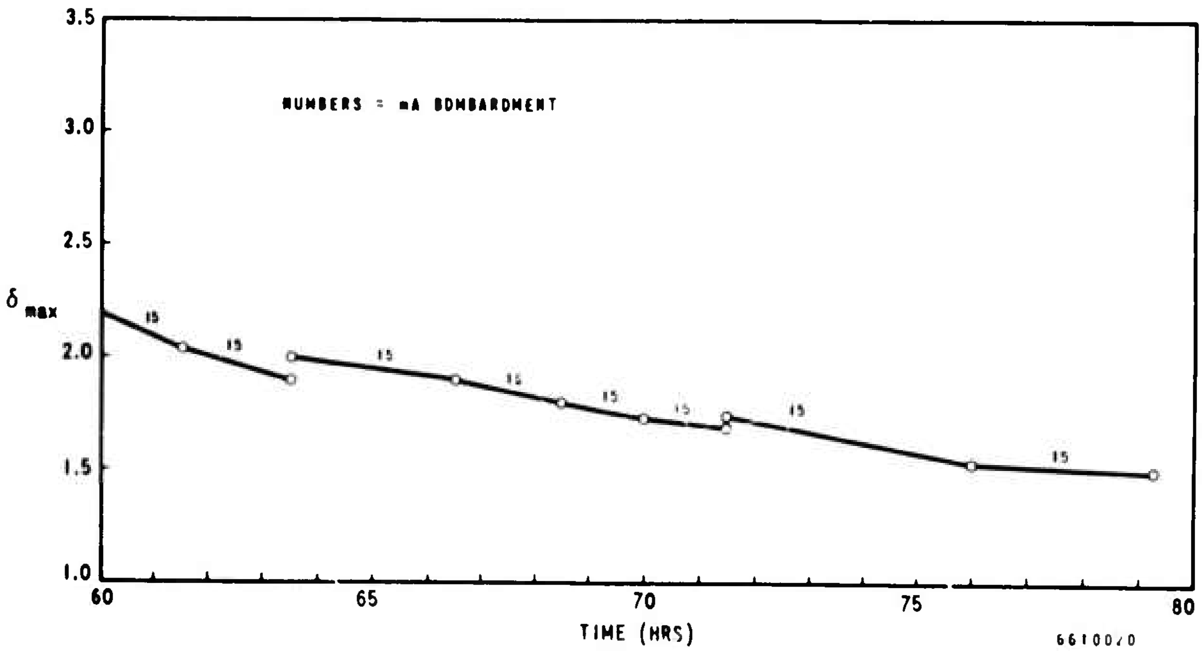
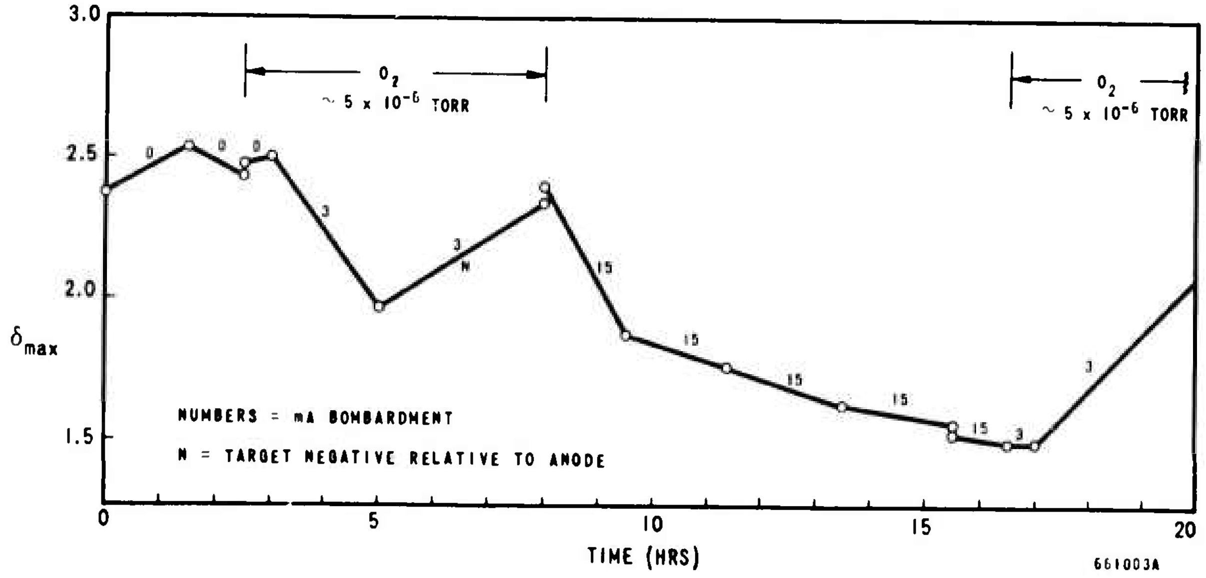


Figure 3. δ_{max} vs EBV Time for 9500Å Evaporated Aluminum on Copper (Sample E-2)

Sheet 2

2.1.1.3 <u>Sample E-3.</u> Sample E-3 was similar to both E-1 and E-2, consisting of a 9500Å layer of aluminum evaporated on copper. The course of δ_{max} as a function of evaluation time in the cold EBV is shown in Figure 4 for a 26-hour period. δ_{max} varied between 2.6 and 1.5. The decrease of δ_{max} with O_2 present and 3 mA bombardment during hours 3 - 5 was unexpected. The decrease in δ during hours 8 - 16.5 due to bombardment at 0.75 A/cm^2 was normal for this sample. Subsequently, a normal recovery due to O_2 was observed during hours 17 - 23. On disassembly of the apparatus, it was noted that the surface of the sample was gold colored rather than the usual color of aluminum. Thin, pure alumina films were not usually colored but rather transparent. The codeposited molybdenum-alumina films were colored. Perhaps, in the present case, some copper diffused into the film from below.



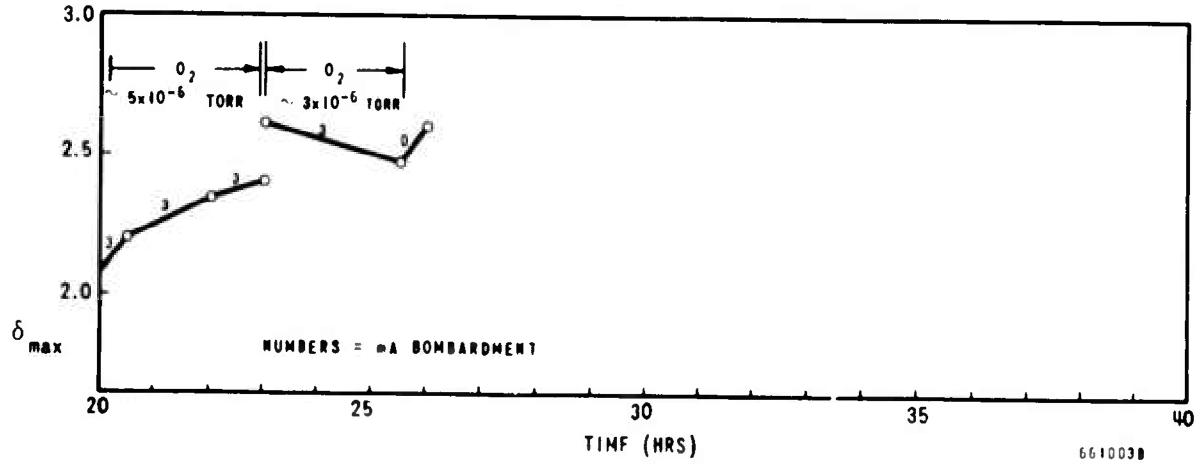


Figure 4. δ_{max} vs EBV Time for 9500Å Evaporated Aluminum on Copper (Sample E-3)

2.1.2 EBV Testing of Anodized-Aluminum Samples

2.1.2.1 Sample A-1. Sample A-1 consisted of an aluminum sample (alloy 6061 - purity 97.5%) anodically oxidized to a depth of 300Å in a tartaric acid solution. The sample surface was highly polished before oxidation. This method is known to produce a non-porous oxide film. The results of 59 hours of evaluation in the EBV are shown in Figure 5. It can be seen that this sample responded to O_2, recovering δ at an O_2 pressure of 5×10^{-6} Torr with simultaneous bombardment at 0.15 A/cm^2. δ_{max} varied from a maximum of 2.7 to a minimum of 1.6. These values are similar to those of the evaporated-aluminum samples, described above.

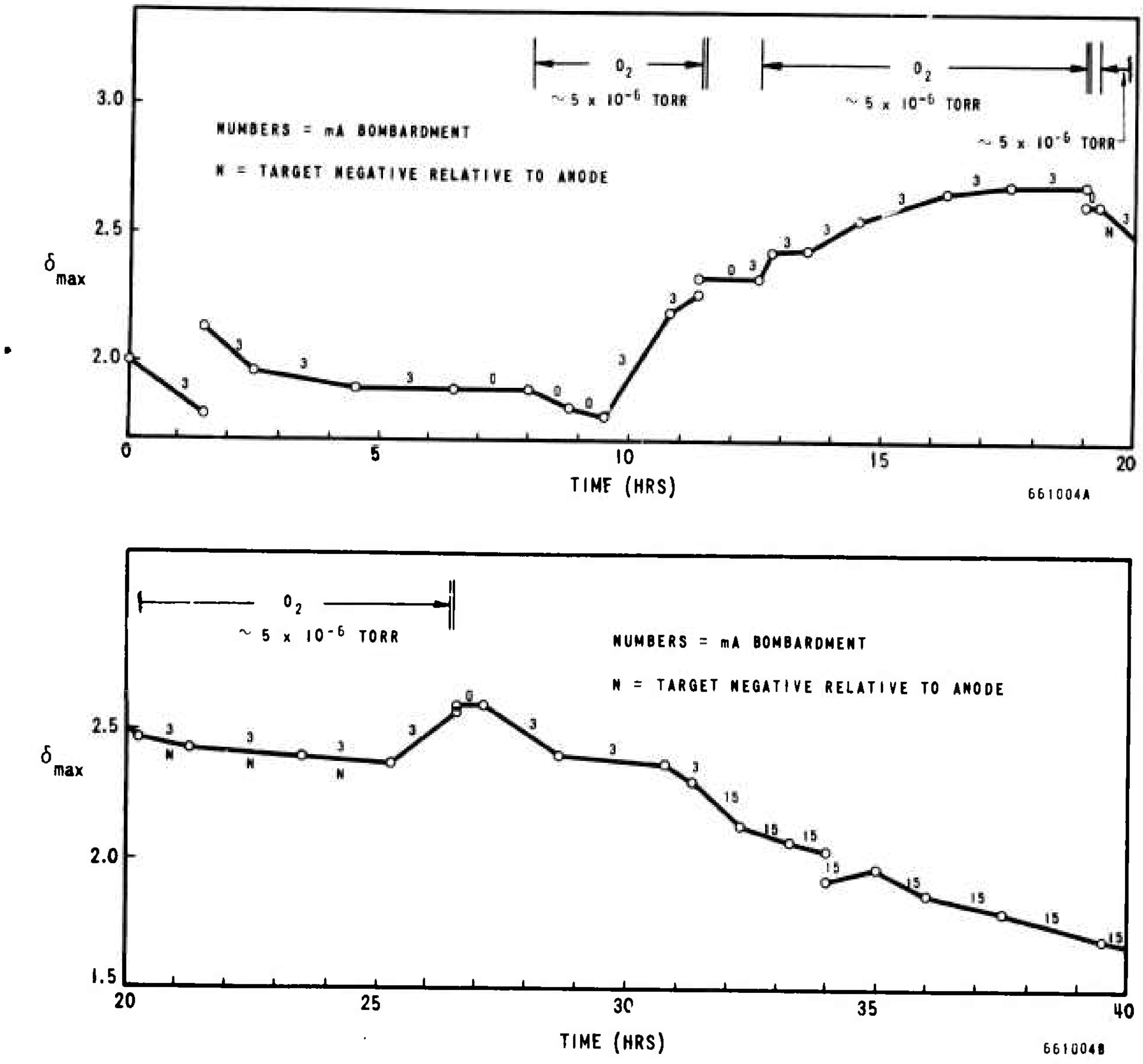


Figure 5. δ_{max} vs EBV Time for 300Å Anodized 6061 Aluminum (Sample A-1)

Sheet 1

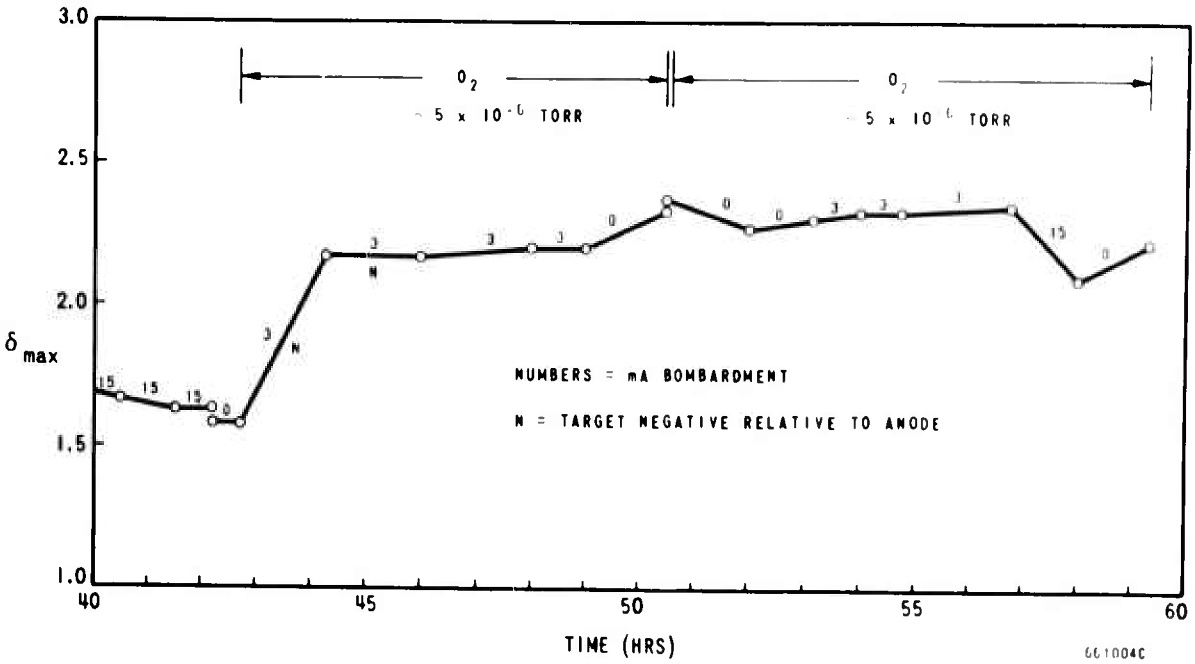


Figure 5. δ_{max} vs EBV Time for 300Å Anodized 6061 Aluminum (Sample A-1)

Sheet 2

2.1.2.2 Sample A-2. Sample A-2 was anodically-oxidized aluminum (alloy 1100 - purity $99.0^{+}\%$). As for A-1, the tartaric acid method was used and the oxide thickness was a nominal 300Å. Figure 6 shows δ_{max} as a function of EBV time during 55 hours of evaluation.

After an initial value of δ_{max} of 1.7, the sample was electron bombarded at 3 mA without O_2 and δ_{max} increased to 3.0. It is suspected that a small air leak was present. The residual vacuum was approximately 3×10^{-7} Torr rather than the usual $2\text{-}5 \times 10^{-8}$ Torr.

Subsequent to the initial period, the value of δ_{max} varied between 3.0 and 2.2. The value of 2.2 persisted during an eight-hour period (hours 42.5 - 50.5) under 0.75 A/cm^2 bombardment. This sample apparently required an oxygen pressure of $< 10^{-7}$ Torr for recovery. The minimum δ_{max} of 2.2 was higher than the usual value of 1.5 to 1.7 for the other aluminum samples.

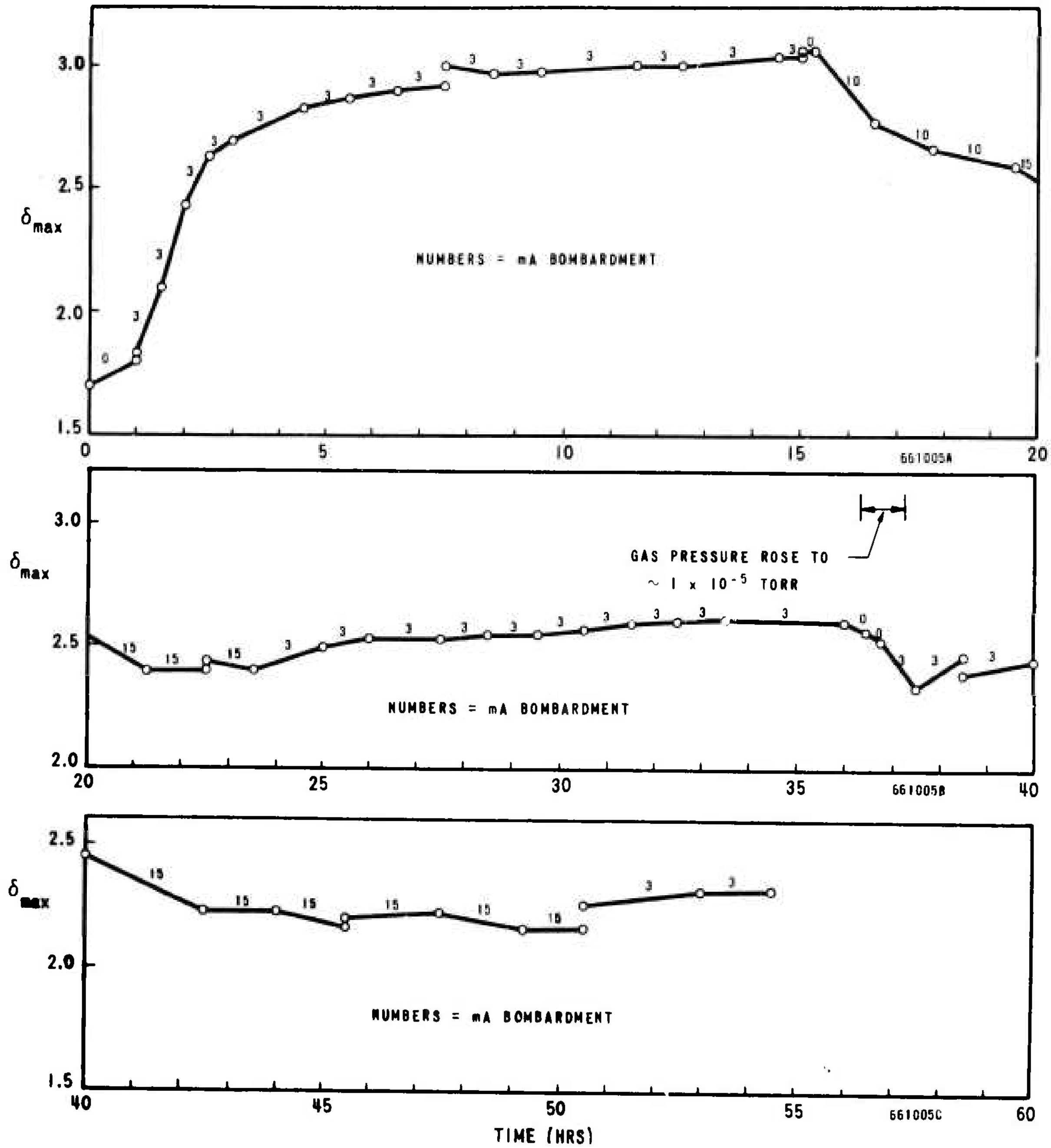


Figure 6. δ_{max} vs EBV Time for 300Å Anodized 1100 Aluminum (Sample A-2)

2.1.3 <u>EBV Testing of Impregnated-Tungsten Sample.</u> An impregnated-tungsten sample was briefly evaluated in the Hot/Cold EBV, the test being terminated by the failure of the sample heater. The initial value of δ_{max} was approximately 1.4 after system bakeout. Heating of the target at an estimated temperature of 1000°C resulted in activation to a δ_{max} of 2.2. At this point, a weld opened in the target-heater connections, thus preventing further sample heating. The record of δ_{max} vs time is shown in Figure 7.

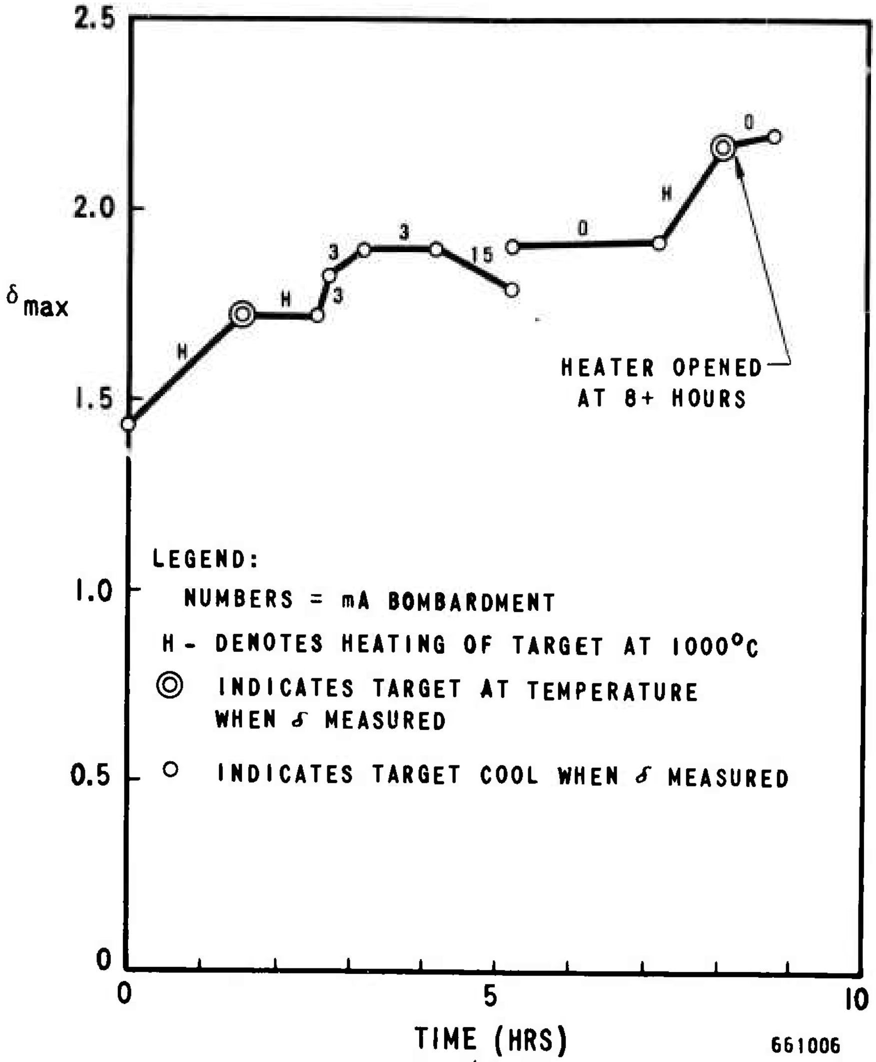


Figure 7. δ_{max} vs Hot/Cold EBV Time for Impregnated Tungsten Sample

3. PHASE B - CFA TESTING

3.1 QKS1397 Test Vehicle

3.1.1 Model No. 8B. Evaluation of cathode emission life of Model No. 8B was conducted on a cathode-pulsed modulator test station during the report period. The tube contained an aluminum (AA-1100 F) emitter 1.645 inch in diameter and 0.570 inch high (19 cm^2 area) and an oxygen dispenser to stabilize the emission. Initially, the operating point selected for test evaluation was:

f_o = 3.4 GHz

p_o = 877 kW peak

P_o = 1770W average

B = 3000 gauss

i_b = 100 amperes

e_b = 28 kilovolts

In Figure 8, the solid line shows the peak tube current and the dashed line shows the oxygen-dispenser heater power, both as a function of time. With an initial peak drive power of 125 kW, a peak current of 100A was obtained at 0.002 duty factor. This level of emission could be maintained for just over an hour, after which it rapidly decayed to 55A. At this time, the peak drive power was raised to 150 kW after changing to a 0.001 duty factor. The emission recovered to 88 A, then a voltage breakdown occurred within the tube (due to temporary loss of rf drive power), and the emission rapidly fell off to 55 A again. The oxygen dispenser was now activated and recovered to 88A. Removal of the oxygen dispenser heater power resulted in a rapid decline of the peak tube current. At this time, the tube was "conditioned" for half an hour with only drive power present. The emission gradually recovered to 80A. An internal tube arc (again due to temporary

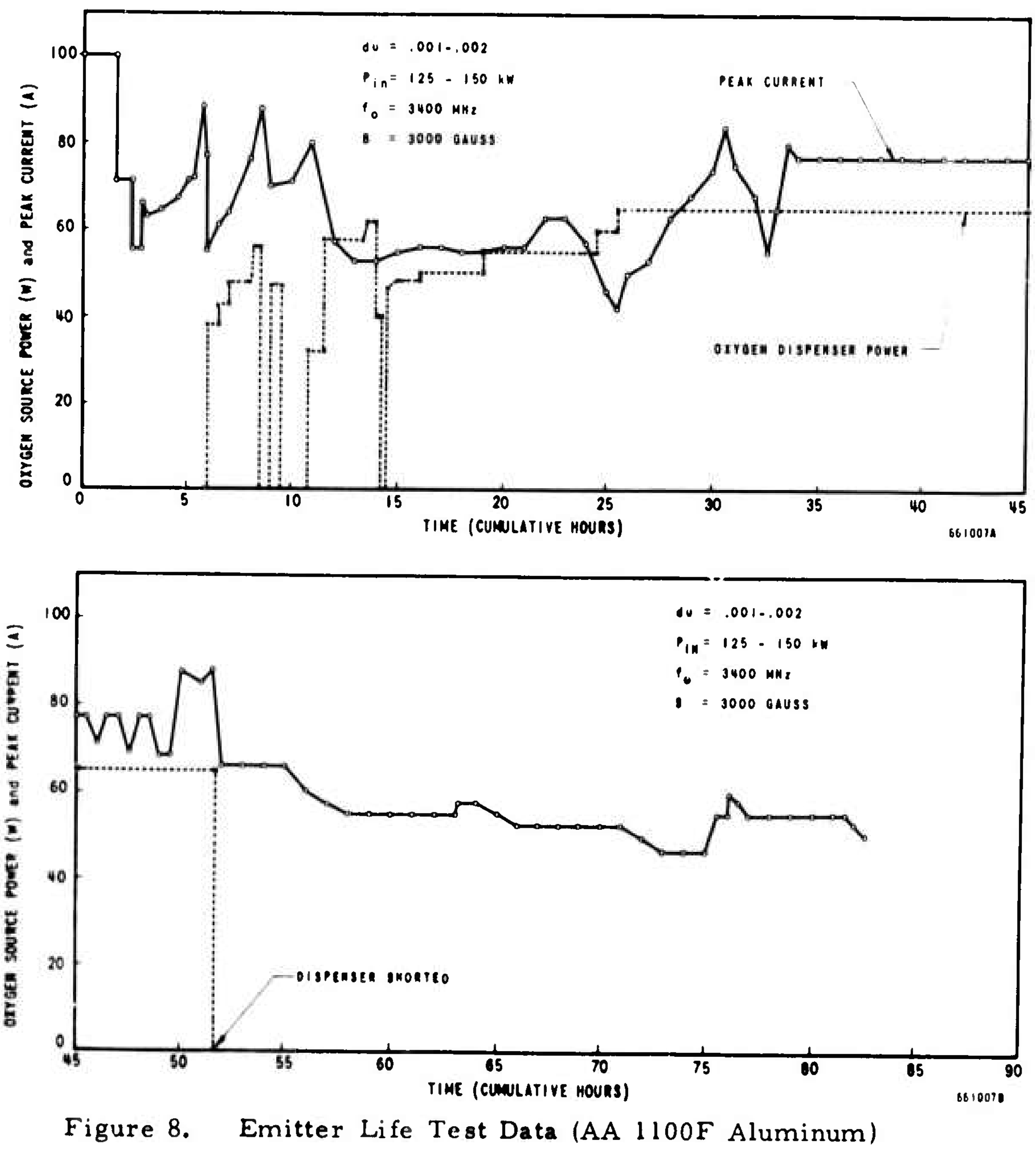


Figure 8. Emitter Life Test Data (AA 1100F Aluminum)

loss of drive power) caused the emission to decline. The emission test continued fairly smoothly (a few tube arcs) into the 52nd hour, with emission stabilized at approximately 77A. At 52^+ hours, the dispenser heater shorted with 65W of heater power. Without oxygen dispenser power to maintain a partial pressure of oxygen in the tube, the emission gradually decreased, and the life test was terminated at approximately 82 hours.

3.1.2 Model No. 8C. The test vehicle was rebuilt as Model No. 8C with a cathode 1.645 inch in diameter and 0.670 inch axial height (22.4 cm^2). The emitter material was aluminum deposited on an OFHC copper base to a thickness of 0.0005 inch. The rebuilt test vehicle was bake-out processed, and at the end of the report period was awaiting availability of a pulse modulator for initial tests.

4. CONCLUSIONS

4.1 Phase A - Materials Evaluation. Two additional evaporated alumina (9500Å) on copper samples showed consistent behavior of rapid recovery with O_2 as for previous sample discussed in the 8th Quarterly Report.

Tests on 300Å Al_2O_3 on Al samples, anodically oxidized in tartaric acid solution, showed good response to O_2 and consistent degradation at high current density electron bombardment without O_2.

4.2 Phase B - CFA Testing. Test of the QKS1397 CFA test vehicle for more than 50 hours has demonstrated stabilized cathode emission from an aluminum cold cathode through the use of oxygen in the pressure range of 10^{-6} to 10^{-5} Torr. The stabilized emission level reached was approximately 4 A/cm^2 at a duty cycle of 0.001.

5. PROGRAM FOR NEXT INTERVAL

5.1 Phase A

a. Perform EBV testing of evaporated-alumina on molybdenum samples.

b. Perform EBV testing of Be samples.

c. Perform EBV testing of BeCu and AgMg samples.

d. Perform Hot/Cold EBV testing of Nickel Cermet samples.

5.2 Phase B

a. Life-test QKS1397 Model No. 8C at the highest cathode-emission level possible with the use of oxygen in the pressure range 10^{-6} - 10^{-5} Torr.

b. Perform additional emission-performance testing of the impregnated-tungsten cold cathode in the QKS1194 test vehicle.

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Security Classification

DOCUMENT CONTROL DATA - R&D

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1. ORIGINATING ACTIVITY (Corporate author) Raytheon Company Microwave and Power Tube Division Waltham, Massachusetts	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP N/A

3. REPORT TITLE

Long-Life Cold Cathode Studies for Crossed-Field Tubes

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Ninth Quarterly Report 15 October 1967 - 15 January 1968

5. AUTHOR(S) (Last name, first name, initial)

Lesensky, L; Arnum, M; and McGeoch, C.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
May 1968	12	0

8a. CONTRACT OR GRANT NO. DA28-043-AMC-01698(E) b. PROJECT NO. 7900-21-223-12-00 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) PT-1782 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) ECOM-01698-9

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13. ABSTRACT

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DD FORM 1 JAN 64 1473

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14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
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